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Relation of Bodily Tension to Electrical Resistance

A DISSERTATION SUBMITTED TO THE GRADUATE FACULTY IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

By
MARTIN MARSHALL WHITE

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RELATION OF BODILY TENSION TO ELECTRICAL RESISTANCE [1]

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PROBLEM

The general problem of this experiment was to compare the electrical resistance of the subject during relaxation with his resistance during bodily tension. The electrical resistance of the human body has been studied by many investigators under various conditions. It has been studied with reference to the activity of the sweat glands by Darrow (1), Einthoven and Roos (3), Georgi (4), Markbreiter (6), Waller (11), and Wells and Forbes (14). It has been studied with reference to circulation by Jung (5), Sidis and Nelson (9), and Waller (11). Ebbecke (2), Feri (5), Jung (5), Darrow (1), Priedeaux (10), Sidis and Kalmus (8), Tarchanoff (5), and Veraguth (5) have studied it with reference to mechanical, chemical, and electrical stimulations. No one, so far as the writer has been able to ascertain, has made any thoroughgoing investigation of the relation existing between bodily tension and electrical resistance. This relationship should not be neglected, for if it is discovered that the electrical resistance does vary with bodily tension, it will be necessary to take this fact into consideration in performing experiments with the galvanic reflex and in interpreting the experiments hitherto performed.

APPARATUS

The electrodes used in this experiment were made of zinc, and were about two centimeters long and a centimeter wide. These electrodes were covered with kaolin paste and an extremely weak solution of zinc sulphate. In the various series the electrodes were attached to different portions of

[1] From the Psychological Laboratory of the University of Chicago. I am indebted to Dr. C. W. Darrow for aid in this experiment.

the hands. The electrodes were connected directly to Leads I and II of Hindle's Electrocardiograph.

The regular hook up of the electrocardiograph was used with two modifications: Lead III was never used, and the Jacquet Chronograph was substituted as a time marker for the tuning fork supplied with the instrument. The photographic attachment was used throughout.

Procedure

The subject lay on a couch with either one or both hands attached to two electrodes. For relaxation the subject was asked simply to rest and if possible to sleep. The latter did not occur with most of the subjects because there were only two relaxation periods of ten minutes each in an experimental period of forty minutes. For tension, the subject was asked (1) to keep all the muscles of his body as tense as possible for ten minutes, (2) to squeeze a dynamometer as tightly as possible for ten minutes, or (3) to work some multiplication problems mentally. Under the first condition (hereafter called Series I) one electrode was attached to the palm of each hand. Under the second and third conditions (hereafter called Series II and III, respectively) the electrodes were attached to one hand. If the subject were right-handed, the electrodes were attached to the left hand, and vice versa. The experiment was conducted as follows: The electrodes were attached to the hands. The lights were turned out. The subject was told to relax for ten minutes. At the end of the ten minute period he was asked to do either (1), (2), or (3) listed above. Then he was asked to relax for ten minutes more; and for a final ten minutes he was asked to repeat the second condition.

At the start of each experimental period, the tension of the string in the electrocardiograph was adjusted so as to give exactly one centimeter deflection for every millivolt of current. In this way it is possible to compare the deflection caused by the subject with the standard amount and to determine exactly the resistance of the subject by the use of Ohm's law. Ohm's law states:

$\frac{E}{I \times R}$ = a constant, in the equation,

$$\frac{E}{I(R + r)} = \frac{Es}{Is(Rs + rs)}.$$

Es = the standardizing E.M.F.,
Rs = the standardizing resistance,
Is = the current (deflection) with the standard R and E (the deflection is proportional to the current passing through the string and the deflection in centimeters is in each case substituted for I),[1]
rs = the resistance of the string,
E = the potential under the conditions of measurement,
R = the resistance under the conditions of measurement,
I = the deflection under the conditions of measurement. In our problem we have the following values:
Es = one millivolt,
Rs = 40,000 ohms,
rs = 3,200 ohms,
E = one millivolt,
I = one centimeter.

This leaves one unknown quantity R which can be readily calculated.

In each series, the states of relaxation and tension are alternated; that is, each period of relaxation is followed by a period of tension and vice versa. This procedure was followed in order to eliminate to some extent the effect of polarization.

Three times a minute one millivolt of current was shot into the circuit. The deflections caused by the millivolt were measured. This measure was then inserted in the equation and the resistance of the subject then computed. Since the millivolt was introduced into the circuit three times a minute,

[1] See Darrow, C. W., "Sensory, Secretory and Electrical Changes in the Skin Following Bodily Excitation," JOURNAL OF EXPERIMENTAL PSYCHOLOGY, X, 3, June, 1927.

on the average thirty measurements were obtained for each subject during each period. Each subject was used only for one forty minute period.

Series I

The electrodes were attached to the palm of each hand in this series. For tension the subject was asked to contract and hold as rigid as possible all the voluntary muscles, especially those of the legs and arms, but to take care not to squeeze the electrodes. The tension period was of ten minute duration and it was followed by a ten minute relaxation period. For each subject two relaxation and two tension periods were obtained.

TABLE I*a*

Series I

Electrodes Attached to Both Hands

1 Subj.	2 Relax	3 S.D.	4 Tens	5 S.D.	6 D.A.	7 S.D.A.
I	47,181	8,766	28,943	4,485	18,138	1,652
II	57,400	5,439	26,250	0,000	31,150	992
III	28,433	4,362	39,635	506	−11,202	802
IV	64,819	6,551	38,111	661	26,708	1,201
V	42,790	5,834	21,058	1,337	21,638	1,095
VI	41,721	1,949	17,778	1,206	23,193	419
VII	72,785	3,244	29,139	2,565	43,546	754
VIII	93,371	5,350	21,985	2,430	72,386	453
IX	98,100	5,867	77,600	3,459	20,500	1,244
X	36,368	2,772	33,921	1,983	2,347	616
XI	34,631	4,183	19,150	137	15,481	763
XII	53,475	5,695	40,970	2,709	15,505	5,875
XIII	23,792	1,320	23,170	0,000	622	240
XIV	64,612	3,243	14,800	0,000	49,812	592

TABLE I*b*

Series I

Electrodes Attached to Both Hands

Subj.	8 Relax	9 S.D.	10 Tens	11 S.D.	12 D.A.	13 S.D.A.
I	68,740	6,697	36,164	1,174	26,576	246
II	53,613	5,290	35,606	3,232	18,013	325
III	†	0,000	24,760	689	*3,673	113
IV	68,910	5,999	†	†	†	†
V	†	†	†	†	†	†
VI	52,050	0,000	22,992	3,694	30,158	213
VII	67,100	7,125	56,750	798	10,350	4,171
VIII	95,200	6,813	23,406	998	71,794	4,299
IX	104,000	0,000	92,266	2,346	11,734	428
X	37,300	1,559	29,739	2,080	7,561	453
XI	23,170	0,000	21,985	530	1,185	957
XII	46,025	2,695	32,892	1,777	13,133	589
XIII	29,000	1,221	30,085	2,141	1,085	450
XIV	42,587	4,758	24,315	9,480	18,275	613

* Difference of average between 2 and 10.

† Values were not obtained due to some defect in apparatus.

In Tables I*a* and I*b* the averages and standard deviations of fourteen subjects for each period are given. The standard deviations are correct only to the third place. Since a difference of a single ohm is of no significance, it was believed to be useless to use any finer measure in obtaining the standard deviation. In the first column the subjects are indicated by Roman numerals. In the second column is the average of the ohmic resistance during the first period of relaxation; in the third column is the standard deviation of this average; in the fourth column is the average of the period of tension followed by the standard deviation. The sixth column contains the difference between the average in relaxation and the average in tension (D.A.). The standard error is placed in the seventh column as an indication of the reliability of the difference. Table I*b* represents in the same way the data obtained during the third and fourth ten-minute periods of experimentation.

While each of the averages given in the table is based upon at least 30 measurements we are not interested in the particular amounts of resistance as much as in the fact that the resistance in relaxation is different from the resistance in tension. To bring this out more clearly Table I*c* is given.

TABLE I*c*

SUMMARY OF TABLES I*a* AND I*b*

Subj.	Columns 2, 4	Columns 8, 10	Subj.	Columns 2, 4	Columns 8, 10
I	G	G	VIII	G	G
II	G	G	IX	G	g
III	L	G	X	g	G
IV	G		XI	G	g
V	G		XII	g	G
VI	G	G	XIII	g	g
VII	G	g	XIV	G	G

G indicates that the resistance is greater during relaxation than during tension and that the difference is thoroughly reliable.

g indicates that the resistance is greater during relaxation than during tension.

L indicates that the resistance is less during relaxation than during tension and that the difference is thoroughly reliable.

In Table I*c* 'g' indicates that the electrical resistance is greater during relaxation than during tension; 'l' indicates that the resistance is lower during relaxation. The capital

case signifies that the difference is thoroughly reliable; that is, the difference is at least four times the standard deviation of the difference.

Summarizing the table, we find that out of 26 ten minute periods:

(*a*) The average electrical resistance is greater during relaxation in 25 periods.

(*b*) The difference in 18 periods is thoroughly reliable. We may conclude therefore that there is a marked tendency for electrical resistance to be greater during general relaxation than during general contracture.

Series II

In this series the subject squeezed the dynamometer with his free hand during the tension period. He was asked to squeeze it as hard as he could, and yet not to such an extent that he would be unable to hold it for ten minutes. Of course there were minor fluctuations in the intensity with which the dynamometer was held; in fact such fluctuations may be responsible for the slight discrepancy obtained in some of our results.

In this series we had eleven subjects, the results from each of which are given in Tables II*a* and II*b*. The method of obtaining the average resistance for the two periods is the same as the method used in Series I. Our results, however, are slightly different from those obtained in the former series.

TABLE II*a*

Series 2

Electrodes Attached to One Hand

1 Subj.	2 Relax	3 S.D.	4 Tens	5 S.D.	6 D.A.	7 S.D.A.
I	26,140	396	25,876	1,216	264	7,021
II	63,216	4,325	52,050	0,000	11,166	249
III	80,533	9,089	55,400	3,493	35,133	1,776
IV	8,797	634	12,614	2,580	−3,817	483
V	11,186	1,523	18,406	3,728	−7,220	755
VI	39,664	964	27,611	1,180	2,053	278
VII	44,800	1,074	31,563	208	13,237	388
VIII	37,120	2,037	30,711	344	6,409	372
IX	34,435	7,712	14,438	7,871	19,977	2,011
X	80,533	1,777	82,800	1,610	−2,267	438
XI	25,070	498	17,025	5,244	8,045	974

TABLE II*b*

SERIES 2

Electrodes Attached to One Hand

Subj.	8 Relax	9 S.D.	10 Tens	11 S.D.	12 D.A.	13 S.D.A.
I	56,237	4,603	52,050	0,000	4,187	84
II	95,000	3,555	68,800	0,000	26,250	649
III	64,612	4,039	52,050	0,000	12,562	737
IV	13,410	0,000	12,770	5,244	640	956
V	†	†	†	†	†	†
VI	52,050	0,000	49,640	435	2,410	79
VII	23,339	3,168	24,260	3,762	1,921	896
VIII	54,400	7,420	36,933	168	27,467	1,356
IX	21,985	3,251	†	†	*7,547	1,874
X	104,000	0,000	86,400	596	17,600	130
XI	36,400	7,712	23,940	3,168	12,461	1,521

* Difference between averages of item in Column 4, Table II*a*, and Column 8, Table II*b*.

† No values obtained due to some defect in apparatus.

With one or two exceptions, the resistance is never as great as that obtained in the first series. This is, no doubt, due to the way in which the electrodes were attached. The difference between the resistance in relaxation and in tension is not as great in this series as in the other. Probably this result can be explained by the fact that in this series the subject was asked simply to squeeze the dynamometer or to contract primarily the muscles of one arm, whereas in the former series he was asked to contract and hold contracted as many muscles as possible. Table II*c* gives a summary of the results of Tables II*a* and II*b*.

TABLE II*c*

SUMMARY OF TABLES II*a* AND II*b*

Subj.	Columns 2, 4	Columns 8, 10	Subj.	Columns 2, 4	Columns 8, 10
I	g	G	VII	G	g
II	G	G	VIII	G	G
III	G	G	IX	G	G
IV	L	g	X	L	G
V	L		XI	G	G
VI	G	G			

G indicates that the resistance of the relaxation state is greater than the resistance of the tension state and that the difference is thoroughly reliable.

g indicates that the resistance of the relaxation state is greater than the resistance of the tension state.

L indicates that the resistance of the relaxation state is less than the resistance of the tension state and that the difference is thoroughly reliable.

From these tables we note that out of 21 pairs of averages:

(*a*) 18 show that the electrical resistance is greater during relaxation than during tension.

(*b*) 15 out of 18 pairs of averages give differences that are at least four times as great as the standard deviation, and hence are to be considered thoroughly reliable.

(*c*) 3 pairs of averages indicate that the resistance is greater during tension than during relaxation.

(*d*) The differences between average resistance during relaxation and average resistance during tension, for those pairs in which the former are greater than the latter, are more than four times as great as the standard deviation, and hence may be regarded as reliable.

Series 3

This series involved silent multiplication as one of the conditions. The object was to see how electrical resistance during so-called mental work differed from that during so-called muscular work. It is entirely out of the question to define here 'mental' and 'muscular' work; but we do wish to point out some of their similarities and differences in connection with our specific problem. Both of them called for the exercise of the voluntary muscles. Perhaps in the 'mental' task the locus of the muscular activity differed from the locus of the activity in the 'muscular' work. Both the mental and muscular work called for an exercise of volitional judgment. The subject must will to do both. The problem of 'muscular' work, however, was largely to maintain the status quo. It was a spastic affair. The subject endeavored to keep the muscles rigidly contracted either in the body as a whole or in a particular segment of the body. The task we used to represent 'mental' work called for a changing bodily state; that is, the individual must perform several operations to accomplish the task. It was not static.

The subject in this series was given two place figures to multiply by each other during the alternate ten minutes of an experimental period of forty minutes. The subject multiplied silently and then gave an oral answer. As soon as he

gave an answer to one problem he was given another. No attempt was made to check the correctness of the answer given. The results are given in Tables III*a* and III*b*, and summarized in Table III*c*.

TABLE III*a*

SERIES 3

Electrodes Attached to One Hand

Mental Multiplication

1 Subj.	2 Relax	3 S.D.	4 Tens	5 S.D.	6 D.A.	7 S.D.A.
I	86,400	7,871	68,800	0,000	17,600	1,436
II	83,400	7,871	61,600	5,577	24,800	175
III	57,636	3,626	21,016	1,394	36,617	2,237
IV	74,950	9,682	33,567	5,019	41,383	1,787
V	68,800	0,000	80,533	7,417	−11,733	1,353
VI	104,000	0,000	26,473	3,737	77,527	682
VII	92,866	7,417	64,722	5,452	28,144	1,353

TABLE III*b*

SERIES 3

Electrodes Attached to One Hand

Mental Multiplication

Subj.	8 Relax	9 S.D.	10 Tens	11 S.D.	12 D.A.	13 S.D.A.
I	57,633	3,626	21,016	1,394	36,617	708
II	104,000	0,000	80,533	4,326	23,470	3,103
III	63,216	3,614	†	†	42,220*	1,768
IV	46,025	2,695	†	†	12,458*	491
V	92,233	4,413	77,600	6,816	14,433	1,481
VI	68,800	0,000	†	†	42,327*	0,000
VII	104,000	0,000	68,800	0,000	35,200	0,000

* Difference in average between item in Column 4, Table III*a*, and Column 8, Table III*b*.

† No values obtained due to some defect in apparatus.

TABLE III*c*

SUMMARY OF TABLES III*a* AND III*b*

Subjects	Columns 2, 4	Columns 8, 10
I	G	G
II	G	G
III	G	G
IV	G	G
V	L	G
VI	G	G
VII	G	G

G indicates that the resistance of the relaxation state is greater than the resistance of the tension state and that this difference is thoroughly reliable.

L indicates that the resistance of the relaxation state is less than the resistance of the tension state and that this difference is thoroughly reliable.

In 14 pairs of averages from seven subjects there is only one that indicates that the electrical resistance is greater during mental multiplication than during general relaxation. The differences in averages of all the instances are thoroughly reliable; that is, the difference is four times the standard deviation.

Tables III*a* and III*b* with reference to Tables I*a*, I*b*, and II*a* and II*b* suggest that 'mental' work causes a greater decrease in electrical resistance than general or local contracture. A valid difference, however, cannot be thoroughly established from our experiments because the subjects were not the same, and the electrodes were attached in different places.

Conclusion

In general it has been found that there is a higher electrical resistance in relaxation than in tension, and that general contracture differs more from general relaxation than does local contracture. These facts are supported by a comparison of general muscular relaxation (1) with general muscular contraction, (2) with localized muscular contraction, and (3) with bodily conditions during silent multiplication.

The importance of a study of this sort is seen when one notes the numerous experimenters who have measured the galvanic response in terms of ohmic resistance. To illustrate, we may consider Smith's (10) investigation. He balanced the subject's resistance in a wheatstone bridge. As soon as the resistance of the subject changed, the bridge would be thrown out of balance and the galvanic string would deflect. It is conceivable that the deflection of the string, which often has been called the galvanic response, may be due to a change of bodily resistance, due to various organic changes. Moreover such effect may be produced not by particular stimuli, but simply by the situation in general.

The same criticism can be applied to a large number of experiments: Feri, Jung, Sidis and Kalmus, Veraguth, and Waller. Of course, it may be that the state of relaxation did not vary in their experiments; but they at least took no cognizance of it.

By an elaboration of the method, it may be possible to get a measure of relaxation or sleep. It is possible too that this method will throw some light on the relation of the so-called mental states to so-called muscular states.

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